

## **General Disclaimer**

### **One or more of the Following Statements may affect this Document**

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

**NASA TECHNICAL  
MEMORANDUM**

**NASA TM X- 72665**

NASA TM X- 72665

(NASA-TM-X-72665) A UNIQUE CONCEPT FOR  
AUTOMATICALLY CONTROLLING THE BRAKING ACTION  
OF WHEELED VEHICLES DURING MINIMUM DISTANCE  
STOPS (NASA) 34 p HC \$3.75 CSCL 13L

N75-23987

Unclas  
G3/37 21854

A UNIQUE CONCEPT FOR AUTOMATICALLY CONTROLLING THE BRAKING  
ACTION OF WHEELED VEHICLES DURING MINIMUM DISTANCE STOPS

DONALD E. BARTHLOME

May 1975



This informal documentation medium is used to provide accelerated or special release of technical information to selected users. The contents may not meet NASA formal editing and publication standards, may be revised, or may be incorporated in another publication.

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665**

1. Report No. TMX - 72665		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle A UNIQUE CONCEPT FOR AUTOMATICALLY CONTROLLING THE BRAKING ACTION OF WHEELED VEHICLES DURING MINIMUM DISTANCE STOPS				5. Report Date May 1975	
				6. Performing Organization Code	
7. Author(s) DONALD E. BARTHLOME				8. Performing Organization Report No.	
9. Performing Organization Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION LANGLEY RESEARCH CENTER HAMPTON, VA 23665				10. Work Unit No.	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION LANGLEY RESEARCH CENTER HAMPTON, VA 23665				13. Type of Report and Period Covered TECHNICAL MEMORANDUM	
				14. Sponsoring Agency Code	
15. Supplementary Notes Interim technical information release, subject to possible revision and/or later formal publication					
16. Abstract  This report outlines test results of a unique automatic brake control system and compares its mode of operation with that of an existing skid control system. The purpose of the test system is to provide automatic control of braking action such that hydraulic brake pressure is maintained at a near constant, optimum value during minimum distance stops.					
17. Key Words (Suggested by Author(s)) (STAR category underlined)  ANTI-SKID SYSTEM			18. Distribution Statement  UNCLASSIFIED - UNLIMITED		
19. Security Classif. (of this report) UNCLASSIFIED		20. Security Classif. (of this page) UNCLASSIFIED		21. No. of Pages 16	22. Price* \$3.25

\* Available from { The National Technical Information Service, Springfield, Virginia 22151  
STIF/NASA Scientific and Technical Information Facility, P.O. Box 33, College Park, MD 20740

### SUMMARY

The report describes a unique automatic brake control system and compares its mode of operation with that of an existing skid control system. The unique system provides an automatic brake control unit which is capable of maintaining brake fluid pressure at a constant, optimum value during minimum distance or 'panic' stops.

## INTRODUCTION

The braking system of conventional wheeled vehicles is designed such that over-application of brakes during minimum distance or "panic" stops can result in a locked wheel condition with attendant potential skidding problems. Numerous systems have been proposed to avoid this problem. One such system is presented in reference 1.

This report describes a proposed system which can limit the angular deceleration of a braked wheel to values that are proportional to the linear deceleration of the vehicle. However, since the angular deceleration of a wheel is directly proportional to the difference between tire torque and brake torque, and since tire torque in turn is dependent upon wheel slip, the system can be said to have the capability of maintaining wheel slip to limits that are proportional to the linear deceleration of the vehicle. In other words, during minimum distance or "panic" stops, the maximum degree of wheel slip allowed by the system will be directly proportional to the degree of deceleration a vehicle is able to attain on a given road surface. In this way, the system not only eliminates the problem of skidding, but has the potential for automatically adjusting to changing braking conditions so as to maximize tire traction on any road surface. The system employs two mutually dependent accelerometers to directly control a solenoid valve which regulates the braking pressure.

This report describes the proposed system, presents results of limited tests on a standard automobile, outlines alternate embodiments

of the system, and compares system features with the system of reference 1 which uses solid state electronic logic.

#### SYSTEM DESCRIPTION

The system consists of a wheel sensor unit mounted on a rear axle of a test vehicle (see figure 1) and a brake pressure stabilization valve (see figure 2) mounted in the brake line leading to the rear wheels.

A simplified isometric view of the wheel sensor unit is shown on figure 3. The unit contains a rotational sensing mass weighing approximately 0.25 lbs., four rotational sensing mass support springs, and a rotational sensing mass support plate. The support plate is secured to the rear axle so that the rotational sensing mass, support spring, and support plate all rotate with the wheel. In addition, the unit contains a translational sensing mass, weighing approximately 0.15 lbs., four translational sensing mass support springs, and a translational sensing mass support plate. The support plate is secured to the body of the vehicle. The rotating rotational sensing mass is separated from the non-rotating translational sensing mass by ball bearings.

When the brakes are applied, the wheel and vehicle decelerate as shown on figure 4. These decelerations produce inertial load  $F_t$  which acts on the translational sensing mass and  $F_r$  which acts on the rotational sensing mass. These inertial loads cause the sensing masses to press against one another by means of ball bearings located at the interface of the two masses. Should the magnitude of  $F_r$  exceed the magnitude of  $F_t$  by some amount, then the rotational sensing mass, in effect, "overpowers" the translational

sensing mass. This action results in a clockwise rotation of the rotational sensing mass relative to the wheel with a corresponding straightening of the rotational sensing mass support springs as shown on figure 4. Simultaneous with this action, the translational sensing mass is forced rearward with a corresponding increase in the deflection of the translational sensing mass support springs. This rearward movement of the translational sensing mass activates a small reed switch which in turn energizes the pressure stabilization valve. The small movement of the sensing masses, relative to one another, can occur in a time span as short as 10 to 15 milliseconds. The reed switch itself closes in a fraction of a millisecond. The preceding sequence of events starting from the instant the sensor unit begins its response, as shown on figure 3, until the pressure in the brake line has actually been stabilized by the valve, occurred in a time span as short as 15 milliseconds.

Because of the design of the wheel sensor unit, any one of the following operating modes can be obtained provided the weights of the two sensing masses are properly proportioned relative to one another. (1) For maximum sensitivity, the rotational sensing mass would be made sufficiently large compared to the translational sensing mass such that the unit would activate at virtually the instant the brake lining contacted the brake drum. This extremely sensitive operating mode would stabilize pressure at such an early stage as to virtually eliminate all braking action. (2) At the other extreme, minimal sensitivity, the rotational sensing mass would be made sufficiently small compared to the translational sensing mass such that the unit would not activate even to the point of "locking" the wheel. (3) Some-

ORIGINAL PAGE IS  
OF POOR QUALITY



where between these extremes there exists an optimum operating mode. For this mode the sensing masses would be sized relative to one another such that the system would permit the wheel to be decelerated to some rate that would occur just prior to the wheel "locking up." At essentially the same instant this rate was attained, brake pressure would be stabilized by the system.

A section view of the pressure stabilization valve is shown on figure 5. When the brakes are applied, brake fluid flows from the master cylinder into region 1 of the valve forcing the valve plunger off the valve seat. Brake fluid then flows into region 2, out the rear wheel port to the rear wheel brake cylinders. When the brake lining contacts the brake drums, pressure throughout the brake system equalizes letting the valve plunger, by virtue of its weight, settle back down on the valve seat. With the valve plunger in this position and the reed switch in the wheel sensor unit closed, the time required to stabilize brake pressure to the rear wheels is essentially the time required to energize the solenoid coil which presses the valve plunger firmly against the valve seat.

#### TEST EQUIPMENT AND RESULTS

The vehicle used to develop and test the system is shown on figure 6. Mounted on a stand next to the driver was an oscilloscope recorder. This recorder, powered by an inverter which received its energy from two 12-volt

ORIGINAL PAGE IS  
OF POOR QUALITY



batteries, was activated manually just prior to applying the brakes and provided a time history of: (1) brake fluid pressure in the front wheels and master cylinder, as obtained from a pressure transducer located in the brake line between the master cylinder and the pressure stabilization valve, (2) brake fluid pressure in the rear wheels, as obtained from a pressure transducer located in the brake line between the pressure stabilization valve and the rear wheel brake cylinders, (3) the deceleration rate of the vehicle, as obtained from a transducer secured to the body of the vehicle, (4) the linear velocity of the vehicle, as obtained from a transducer attached to the fifth wheel, (5) the angular velocity of the rear wheel containing the sensor unit, as obtained from a transducer secured to the rear axle housing and activated by the rotating tire, and (6) the opening and closing of the reed switch in the sensor unit, as obtained from the solenoid coil current.

In addition to the oscilloscope recorder, two digital meters were mounted on the dash of the vehicle in full view of the operator. These meters, activated by transducers secured to the fifth wheel, indicated: (1) the velocity the vehicle had at the instant the brakes were applied, and (2) the distance traversed by the vehicle from the point at which the brakes were first applied. These meters were used as displays to assist the operator and not as a source of test data.

The braking capability of a tire on a given surface is related to wheel slip in a manner indicated by the curve shown on figure 7. Mathematically, wheel slip is the difference between the vehicle's velocity and the peripheral velocity of the wheel (taken relative to the vehicle as a frame of reference) divided by the vehicle's velocity and the result expressed as percentage. When the brakes are applied, a tire develops traction torque by "slowing down" relative to the vehicle. Maximum traction torque or tire torque is attained when wheel slip reaches a value between 10 and 20%, depending upon braking conditions. This value is indicated by point P on figure 7. If brake torque should exceed tire torque to the extent that wheel slip exceeds the value indicated by point P, the brakes will lock the wheel unless brake pressure is relieved.

The first test runs using the system were all made at the same velocity (approximately 20 mph) and on the same section of roadway. These runs started with the weight of the rotational sensing mass small when compared to the weight of the translational sensing mass. As a result, the rear wheels had to attain a rather high degree of wheel slip with attendant high degree of angular deceleration in order to activate the system. The degree of wheel slip at which activation occurred on the first test run, is depicted hypothetically as run #1 on figure 7. After this run and each subsequent run, the weight of the rotational sensing mass was increased slightly for the next run. Each increase caused the unit to activate sooner and at a lesser degree of wheel slip than was required for the previous run.

These runs are depicted hypothetically as runs #2 and #3 on figure 7. This process was repeated until a point (run #4 on figure 7) was reached where tire traction was a near maximum and brake pressure could be stabilized without attendant wheel lock. A number of runs were then made at this weight setting to determine the repeatability of the system.

At this stage in the test program, the system had demonstrated a satisfactory capability for automatically stabilizing brake pressure to the rear wheels at a value that provided near maximum tire traction during minimum distance stops at 20 mph on a particular section of roadway. It was now necessary to investigate what effect changes in operating parameters such as vehicle velocity and road surface might have on this performance.

Figure 8 shows data from a minimum distance stop made without the aid of any type of skid control system. At  $t = -0.01$  second, the vehicle was coasting at 45 mph as represented by the curve for vehicle velocity. At  $t = 0$  second, the brakes were applied as indicated by the increase in the two brake fluid pressure curves. (The difference in magnitude of these curves, during the initial stage of braking action, was due primarily to a pressure drop across the pressure stabilization valve.) At  $t = 0.2$  second, the brake lining contacted the brake drum causing the vehicle to decelerate as indicated by the increase in the curve representing the vehicle's deceleration. At  $t = 0.28$  second and a rear wheel brake fluid pressure of 200 psig, the rear wheels began to oscillate as indicated by the waves forming in the curve that represents their angular velocity. These oscillations, which had a period of approximately 60 milliseconds, were observed

during the first half of virtually every run where the test system was in use. Although the reason for their occurrence is not know, they were interpreted as indicating that wheel slip was approaching the vicinity of point P on figure 7. At  $t = 0.5$  second and a brake pressure of 400 psig, the rear wheels had reached or just passed point P, the point of maximum tire traction. At  $t = 0.7$  second, the wheels had ceased to rotate.

Figures 9 through 12 represent a sample of numerous stops made to determine the effect of changes in vehicle velocity and road conditions on the system's performance as previously established at 20 mph on a particular section of roadway. These stops were made at velocities ranging from 20 to 50 mph on wet and dry concrete and asphalt. The results of these stops indicated that, within the range of values tested, the system demonstrated a capability for stabilizing brake pressure at a near optimum value regardless of vehicle velocity and road surface conditions, and for maintaining this pressure constant throughout the stop.

The conception of the test system was based on the belief that a brake pressure, stabilized when a tire had reached a point of maximum traction, could produce a greater retarding effect on the vehicle's velocity than an oscillating brake pressure. This premise, however, required that a constant application of brake pressure produce an essentially constant braking effect. Unfortunately, the brakes on the test vehicle were of the drum type which exhibit brake fade. In other words a constant application of brake pressure does not produce a constant braking effect, at least not for the severe braking action required by the test program.



The effect of brake fade is believed to be evident on figures 9, 10, and 11, where initially a given brake pressure appears to maintain the rear wheels in a condition of impending wheel lock. That is, the wheel's angular velocity initially oscillates at a rapid rate. Half-way through the stops, however, these oscillations disappear and the wheel's motion becomes quite stable. This action could easily stem from a loss in friction between lining and drum as the temperature of the brakes increased. To further substantiate this conclusion, figure 12 shows a stop that occurred on several occasions wherein the system permitted an overpressurization to the extent that wheel slip reached 70% and then suddenly returned to approximately 10%. Evidently, the rapid rise in the temperature of the brakes gradually permitted tire "spin up" torque to exceed tire brake torque. As a result, the wheel's velocity increased.

In addition to brake fade, drum brakes are also characterized by an ability to self-energize. This ability, however, is directly proportional to the friction coefficient (reference 2). Consequently, as braking friction decreased during a test run, so also did the self-energizing capability of the brakes.

In summation, it can be stated that as the temperature of the brakes increased, the effect of brake fluid pressure as stabilized by the system was diminished not only by a loss of braking friction, but by a reduction in the ability of the brakes to self-energize.

A further problem observed during the feasibility test program was the expansion of the brake drums. This condition allowed the stabilized brake fluid pressure to decrease in magnitude as the brake lining moved outward with the expanding drum. For example, during a 50 mph stop the stabilized pressure dropped from 480 to 360 psig.

The effect of the preceding conditions on the performance of the test system could have been eliminated or greatly reduced through the use of caliper disc type brakes.

#### SYSTEM COMPARISON

Let it be assumed that when the stop shown on figure 8 was made, the test vehicle had been equipped with a skid control system such as that described in reference 1. If this had been the case, then between  $t = 0.5$  and  $t = 0.7$  second, an electro-magnetic speed sensor on one of the rear wheels would have input an activation signal to another component of the system termed the logic controller. The logic controller would in turn have memorized this signal for approximately 140 milliseconds. If, during this interval the wheel speed fell a predetermined amount below this memorized value, with the brakes applied, the logic controller would have energized the pressure modulator to effect pressure decay. (The percentage change in speed from the memorized value required to decay pressure is 5% if vehicular deceleration is below  $16 \text{ ft/sec}^2$  or 15% if vehicular deceleration is above  $16 \text{ ft/sec}^2$ ). The pressure modulator in turn would then have begun



reducing pressure to the rear wheels. As brake pressure was reduced, the rear wheels would cease to decelerate and begin to accelerate. When they reached a slightly positive acceleration value, say around 0.2 "G", pressure decay would have been discontinued and a low pressure build initiated. If the wheels had continued to accelerate so as to reach a value of 2.2 "G", in spite of increasing brake pressure, the system would have begun increasing pressure at a more rapid rate. This fast build rate would have continued until the wheel's acceleration fell below the 2.2 "G" level at which time the system would have reverted back to the low pressure build rate until one of the wheels reached incipient lock, when the cycle would have been repeated.

The wheel sensor for the anti-lock system of reference 1 reacts solely to the deceleration rate of the wheel. Consequently, system reaction is limited to high degrees of wheel deceleration. While this characteristic enables the system to prevent wheel lock, it may limit its ability to maximize tire traction on all braking surfaces. On the other hand, wheel sensor response of the test system is based not upon a single deceleration, but upon the ratio of two decelerations - the wheel's and the vehicle's. As long as braking is normal, a stabilization of vehicular deceleration will be accompanied by a corresponding stabilization of wheel slip. If, however, braking is abnormal, such as during a panic stop, vehicular deceleration will again stabilize at some maximum value, but wheel slip will continue to increase. It is at this instant that the test system stabilizes brake pressure to the wheels thereby demonstrating its potential to maximize braking action on all operating surfaces.

## ALTERNATE EMBODIMENT OF THE SYSTEM

Although the test system has the ability to increase brake pressure, it was not capable of decreasing pressure as might be required when going from a high to a low friction surface. This capability might be obtained in the following manner. Figure 5 shows a cross sectional view of the pressure stabilization valve wherein an "O" ring is present between the valve seat and retainer. (This "O" ring was not present in the valve as used during the test program.) As the unit is assembled, this "O" ring is compressed. The degree of compression, however, is such that when the solenoid is energized with 6-volts of direct current, the valve plunger will contact the valve seat with a force sufficient to close the valve, but not sufficient to move the valve seat from its original position. If, on the other hand, the solenoid voltage is increased from 6 to 12 volts, the force exerted on the valve plunger will then be sufficient to compress the "O" ring to the extent that the valve seat will be brought into contact with the retainer. This action would produce an increase in the volume of region 2 thus decreasing the pressure on the rear brakes.

The increase from 6 to 12-volts can be attained in the following manner. Referring to figure 13, point 1 indicates the beginning of vehicle deceleration. At point 2, the deceleration of the wheel reaches a value which, relative to the deceleration of the vehicle, is sufficient to close sensor switch No. 1. This action energizes the pressure stabilization valve

which in turn stabilizes pressure in the controlled wheel. At points 3, 4, 5, and 6 the wheel and sensor undergo typical oscillations which indicate marginal stability between the tire and road surface. Since the time spans from 3 to 4 and 5 to 6 (representing periods when the valve is deenergized) are small, the valve does not open. At point 7 however, brake pressure due to a sudden drop in tire traction, suddenly becomes excessive causing the wheel's deceleration (see sharp decrease in the wheel's angular velocity at point 7) to reach a value double or even quadruple that which occurred at points 2, 4, and 6. As a result, the inertial load on the rotational sensor is greatly increased thus enabling it to overcome an elastic rotational limit device. This action activates another reed switch (No. 2) in the sensor unit. The closure of switch No. 2 allows current from the 12-volt battery to bypass a resistor and switch No. 1 by going through switch No. 2. As a result the applied voltage to the stabilization valve is increased from 6 to 12-volts. The subsequent increase in electromagnetic force enables the valve plunger and valve seat (see figure 5) to move a few thousandths of an inch by compressing the "O" ring. Consequently, pressure in the system drops and the wheel's velocity begins to increase until switch No. 2 opens as indicated by point 8 on figure 13. With the opening of switch No. 2 the voltage to the stabilization valve drops back to 6-volts thus enabling the compressed "O" ring to move the valve plunger and valve seat back to their original position. If the pressure at the controlled wheel is still excessive, the process will be repeated as shown at point 9 on figure 13.

During the test program it was observed that if the test system were not operating, locking of the rear wheels always began at the instant the vehicle reached its maximum degree of deceleration (see  $t = 0.52$  sec. on figure 8). Although brake pressure continued to increase past this point, its increase did not affect the deceleration rate of the vehicle. Indeed the only observable effect of this continued increase in brake pressure (assuming negligible brake fade), was the locking of the wheels. From these observations it might be concluded that at approximately  $t = 0.52$  seconds on figure 8, tire traction suddenly reached its maximum value. This condition is evident at this time by an abrupt stabilization of vehicular deceleration. Therefore, if at this instant brake pressure had been stabilized in all wheels, wheel lock would have been eliminated. To accomplish this, sensors need only be located in the rear wheels. These sensors would be combined with two pressure stabilization valves - one for the front brakes and the other for the rear. Both valves would stabilize pressure at the same value when activated simultaneously by one or the other of the two rear wheel sensors. The front wheel valve would maintain this value of pressure constant, but the rear valve would have to oscillate the pressure in order to prevent rear wheel lock. This would be necessary, because the pressure would have been stabilized late for the rear wheels and would, therefore, be from one to three hundred psig (depending upon operator's rate of pressure application to brake pedal) in excess of that value which could be maintained constant without wheel lock. Cycling of rear wheel pressure could be obtained by allowing the sensor switch to apply 12 volts rather than 6 to the valve shown on figure 5. This would compress



the "O" ring and reduce pressure thus allowing the rear wheels to accelerate and the sensor switch to open. When the switch opened, the valve would deenergize and the compressed "O" ring would move the plunger back to its original position, thus returning the brake pressure to its initial value.

## CONCLUSIONS

The braking control system described in this report demonstrated the potential for preventing tire skid during "panic" stops. Test data validate that the system automatically selects a value of pressure which produces a near maximum braking effort and then maintains this pressure essentially constant throughout the remainder of the stop.

System performance would have been improved had the test vehicle been equipped with disc rather than drum brakes.

Observations made during the test program indicate that an acceptable four-wheel skid control system may only need sensors on the rear wheels.



## REFERENCES

1. Douglas, J. W. (Chrysler Corp.) and Schafer, T.C.: The Chrysler "Sure-Brake" - The First Production Four-Wheel Anti-Skid System, 710248, Society of Automotive Engineers, Automotive Engineering Congress, Detroit, Michigan, January 11-15, 1971
2. Huck, SAE, Pt. I, 1926, p. 455

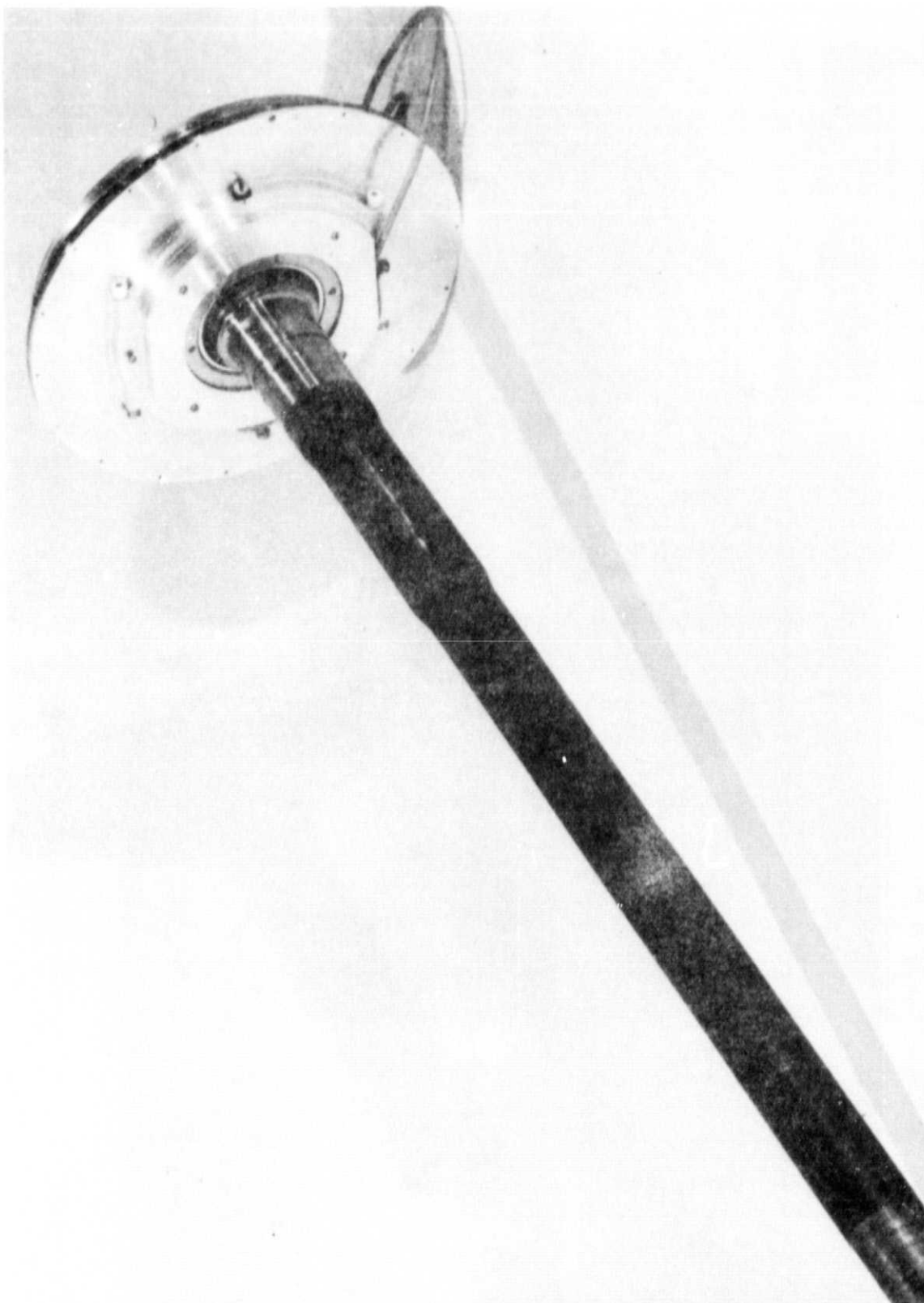


Figure 1.- Wheel sensor unit mounted on rear axle

ORIGINAL PAGE IS  
OF POOR QUALITY

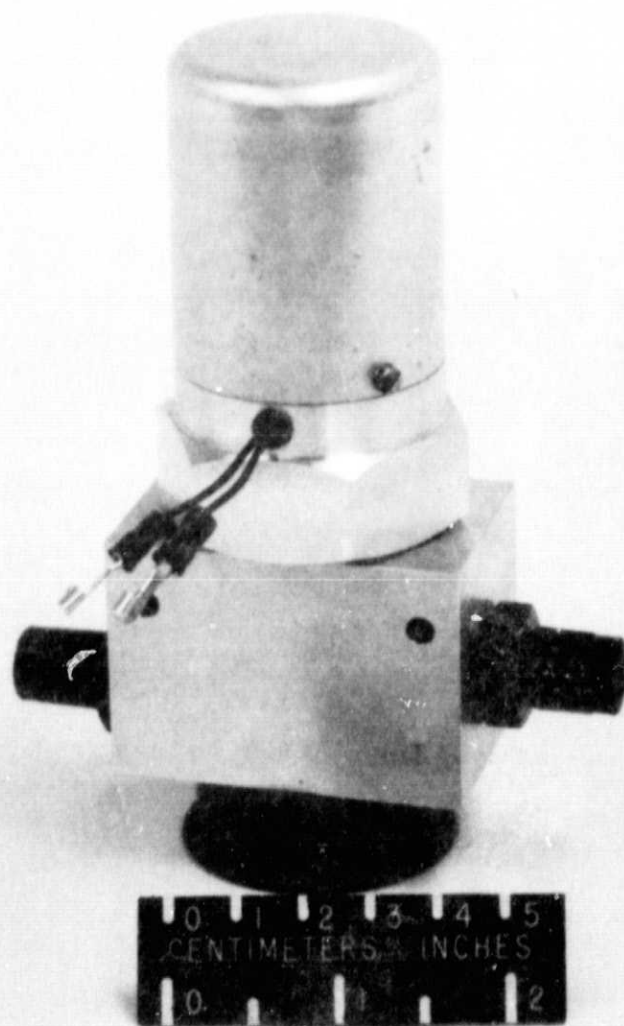


Figure 2.- Brake pressure stabilization valve

ORIGINAL PAGE IS  
OF POOR QUALITY

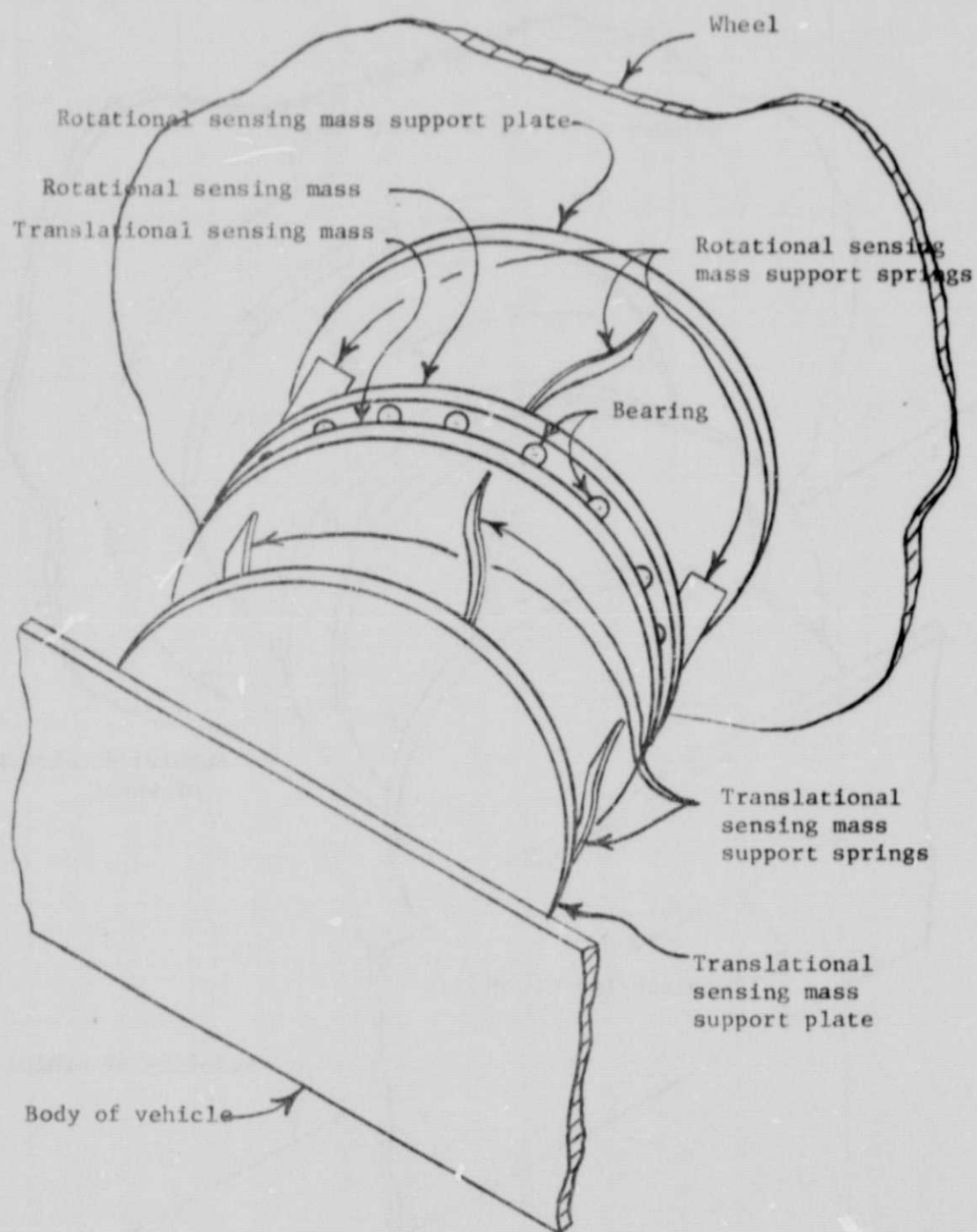
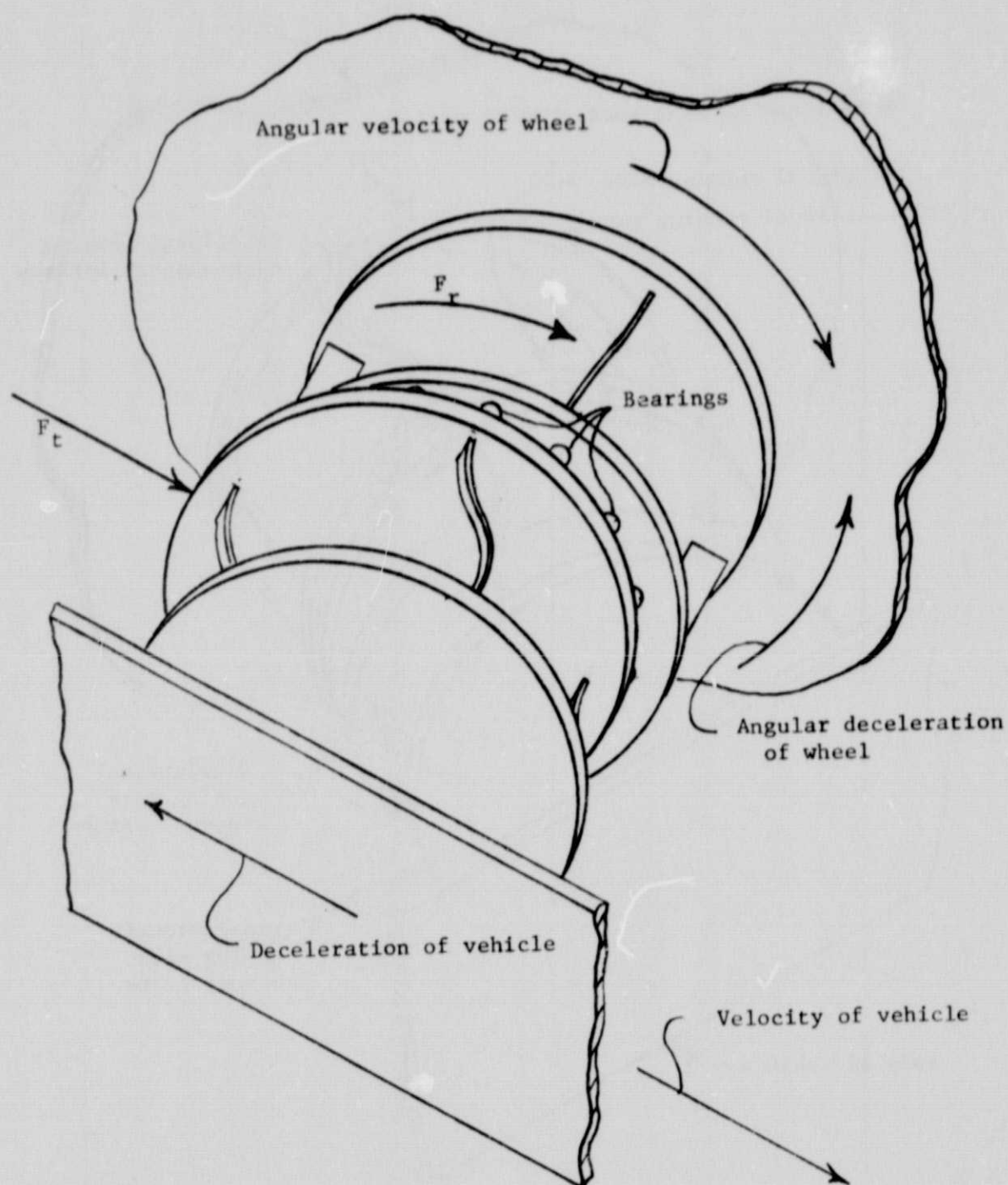


Figure 3. - A simplified isometric view of the wheel sensor unit.



ORIGINAL PAGE IS  
OF POOR QUALITY

Figure 4. - Wheel sensor unit in an activation mode.



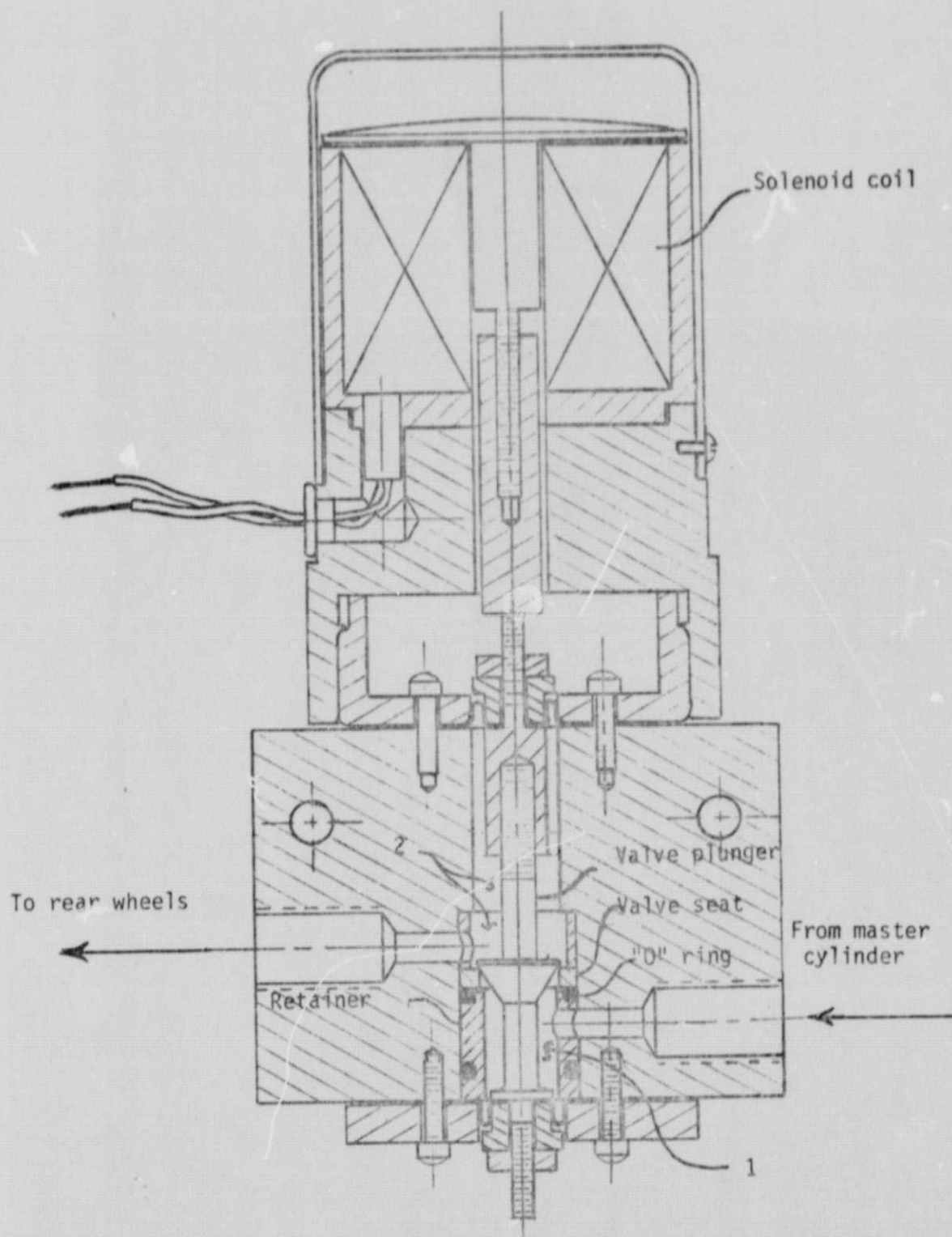


Figure 5.- Modified brake pressure stabilization valve



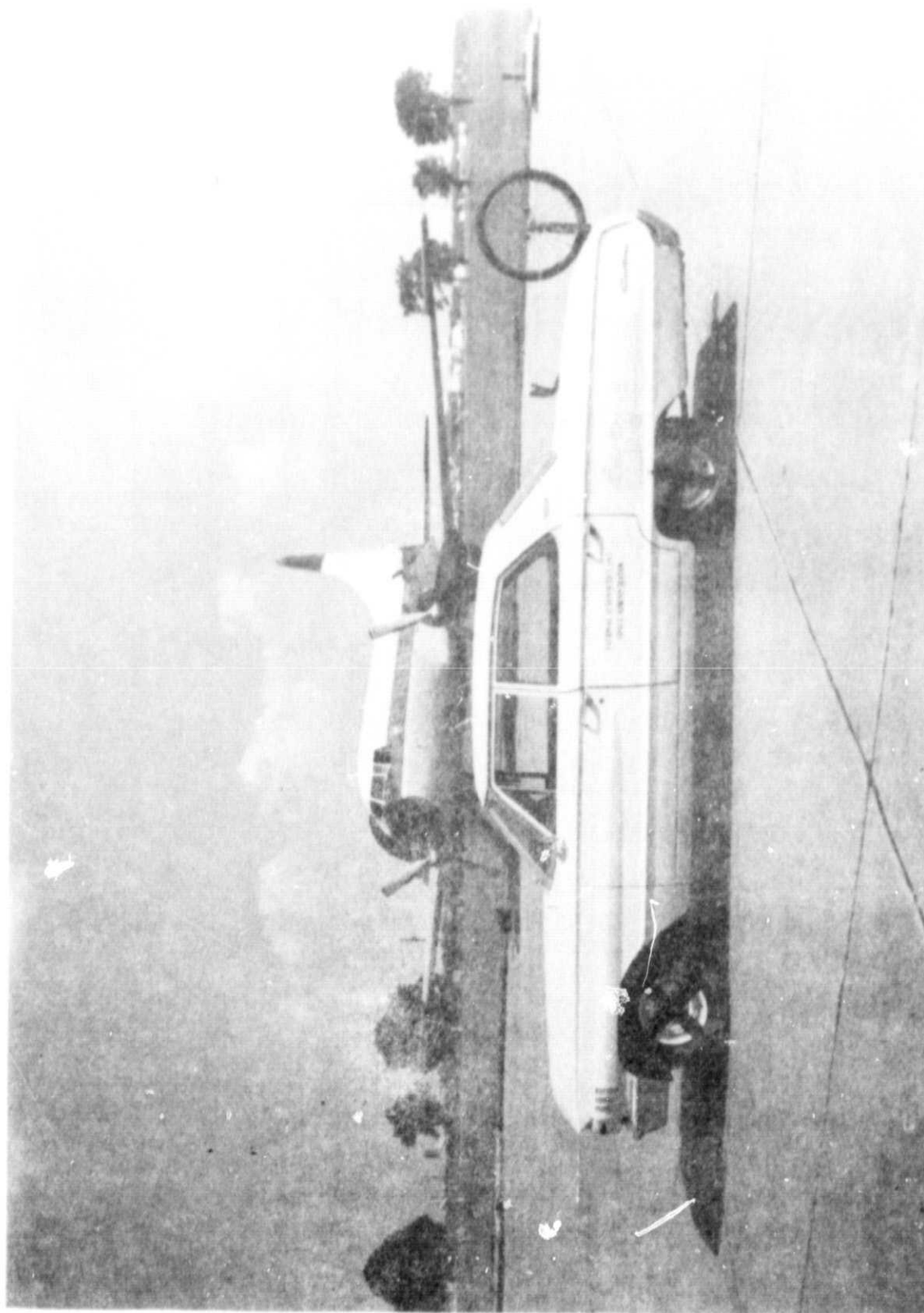


Figure 6. - Vehicle used to develop and test the system

ORIGINAL PAGE IS  
OF POOR QUALITY

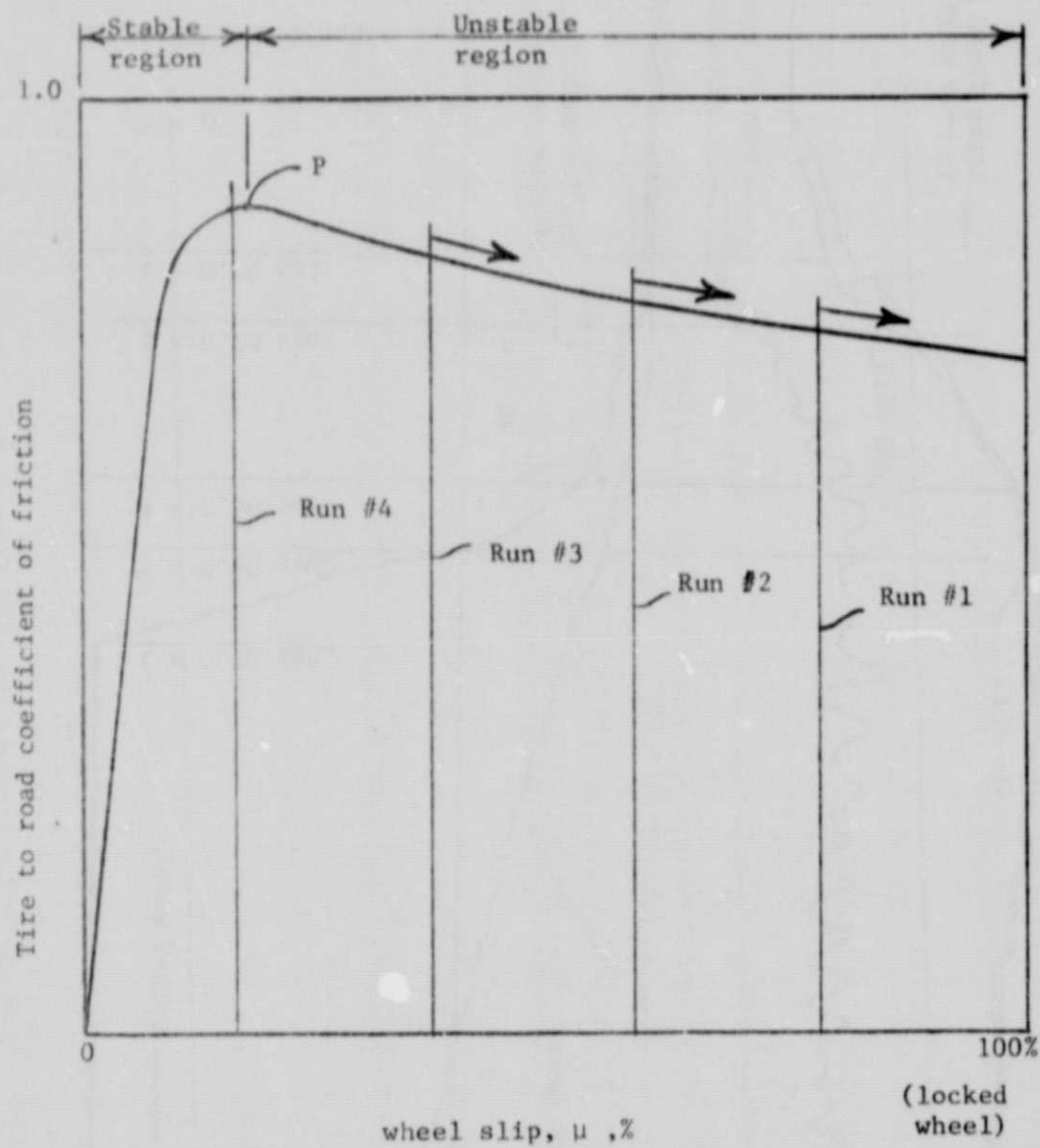


Figure 7. - A typical curve of wheel slip versus tire to road coefficient of friction

ORIGINAL PAGE IS  
OF POOR QUALITY

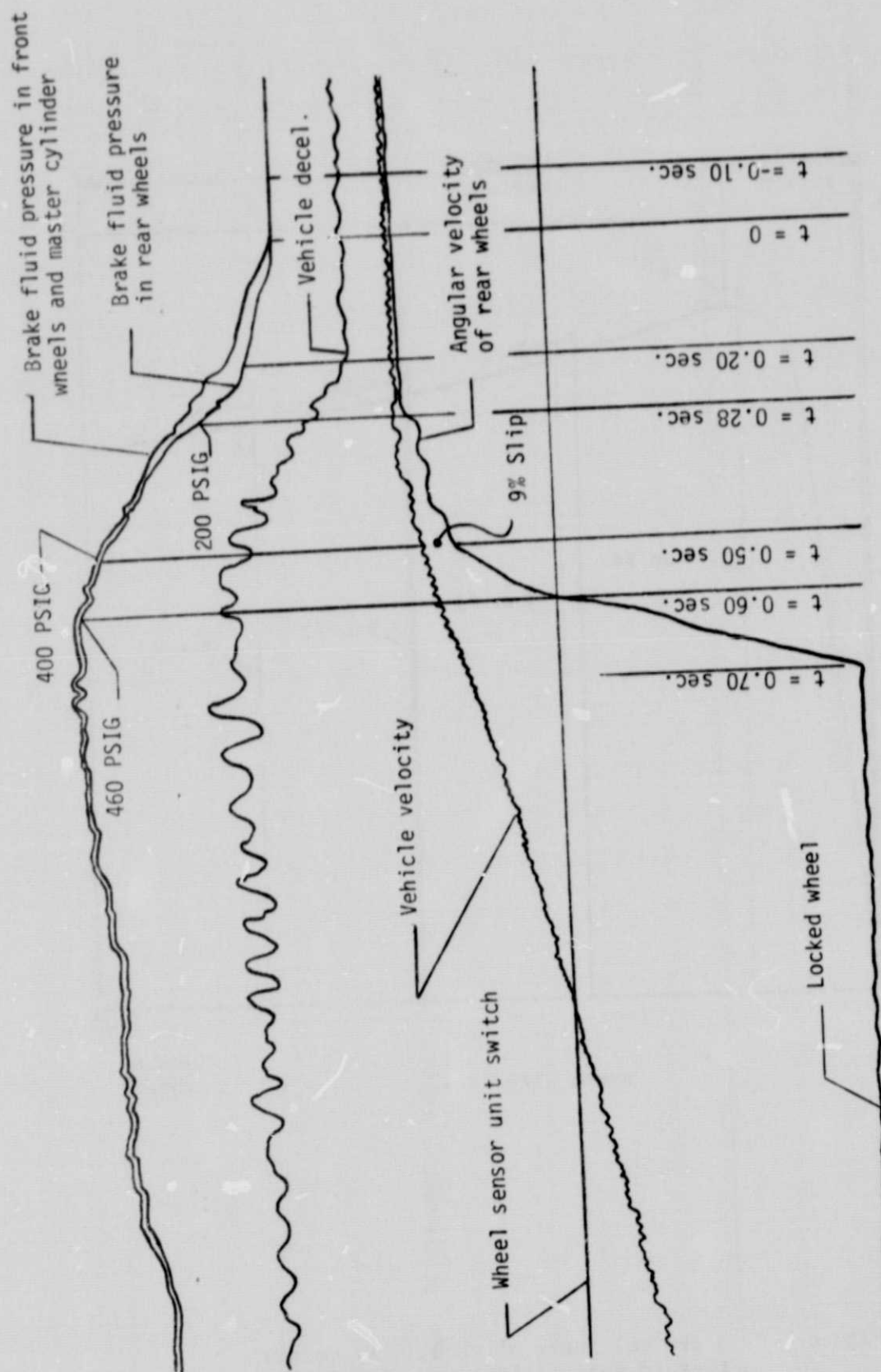


Figure 8. - Minimum distance stop made without the test system - dry asphalt - 45 mph.

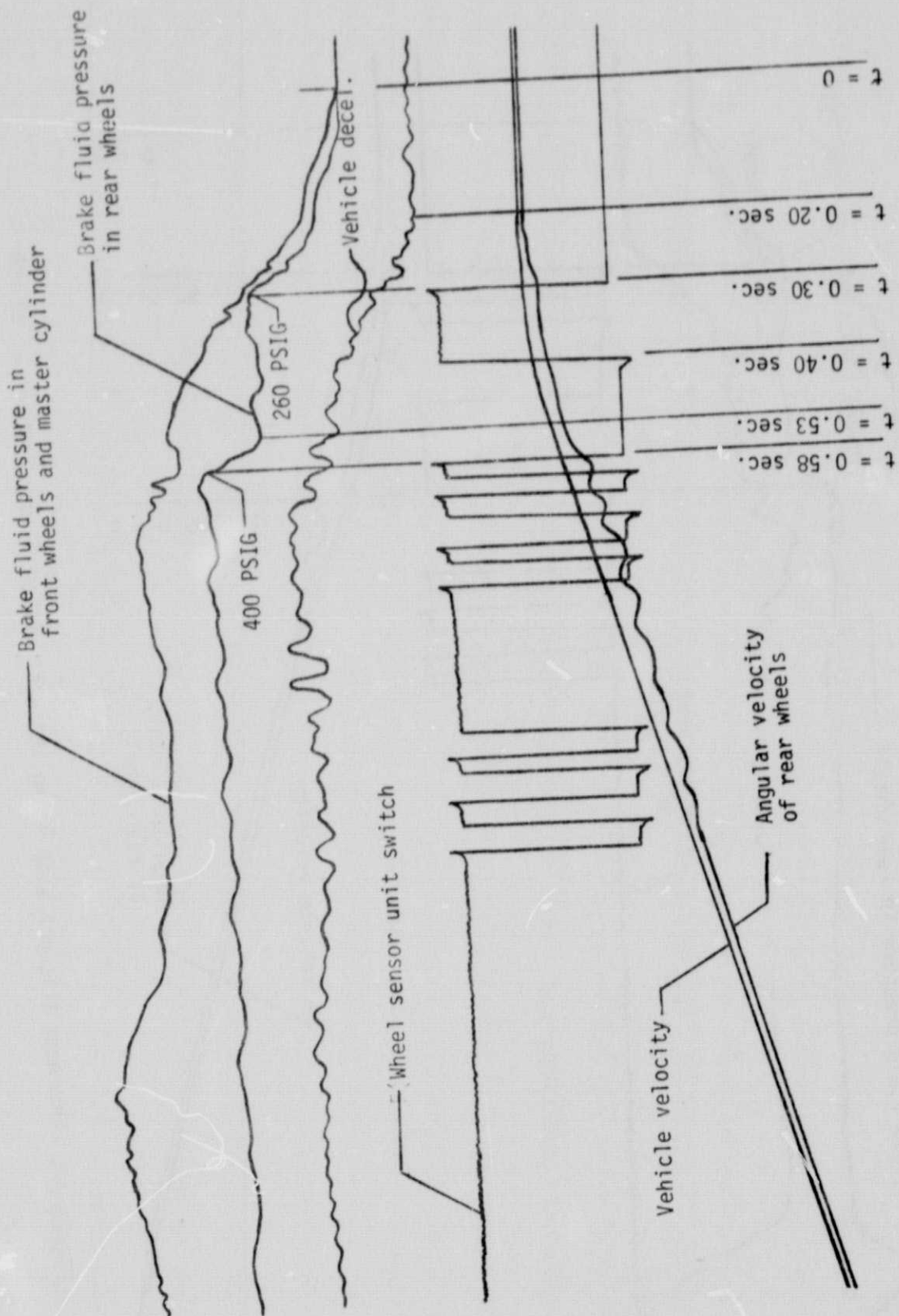


Figure 9. - Minimum distance stop using the test system - wet concrete - 40 mph

ORIGINAL PAGE IS  
OF POOR QUALITY



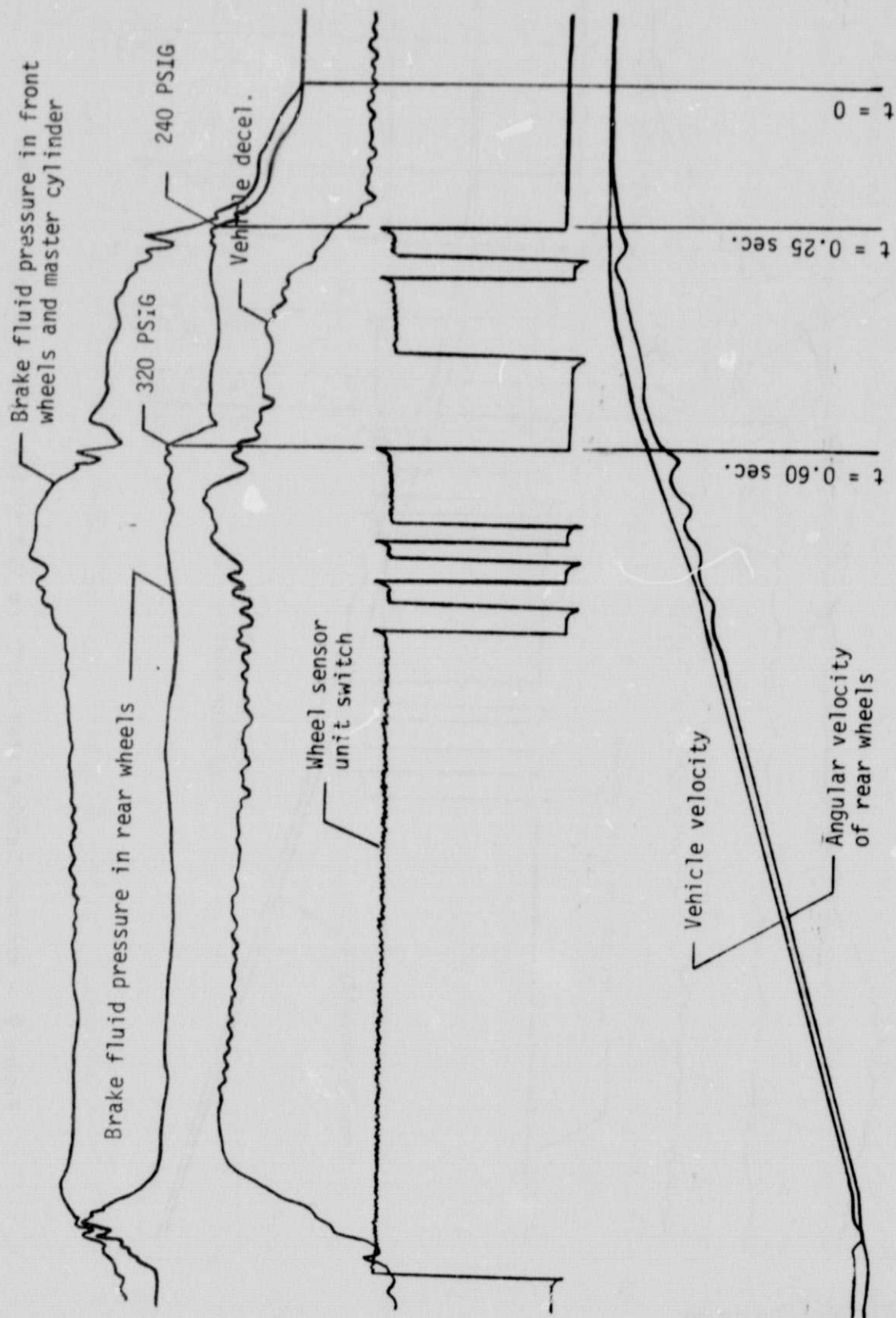
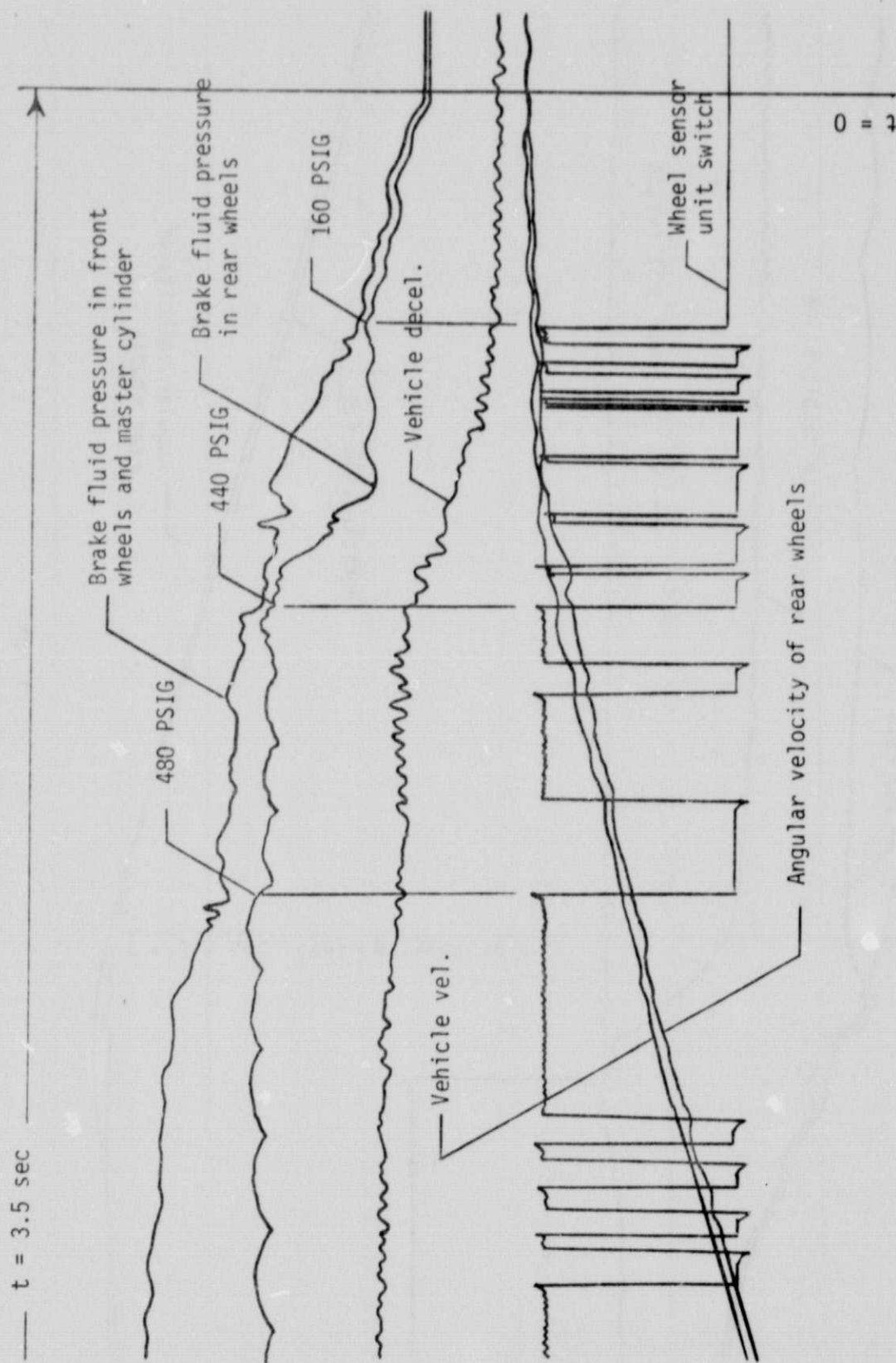


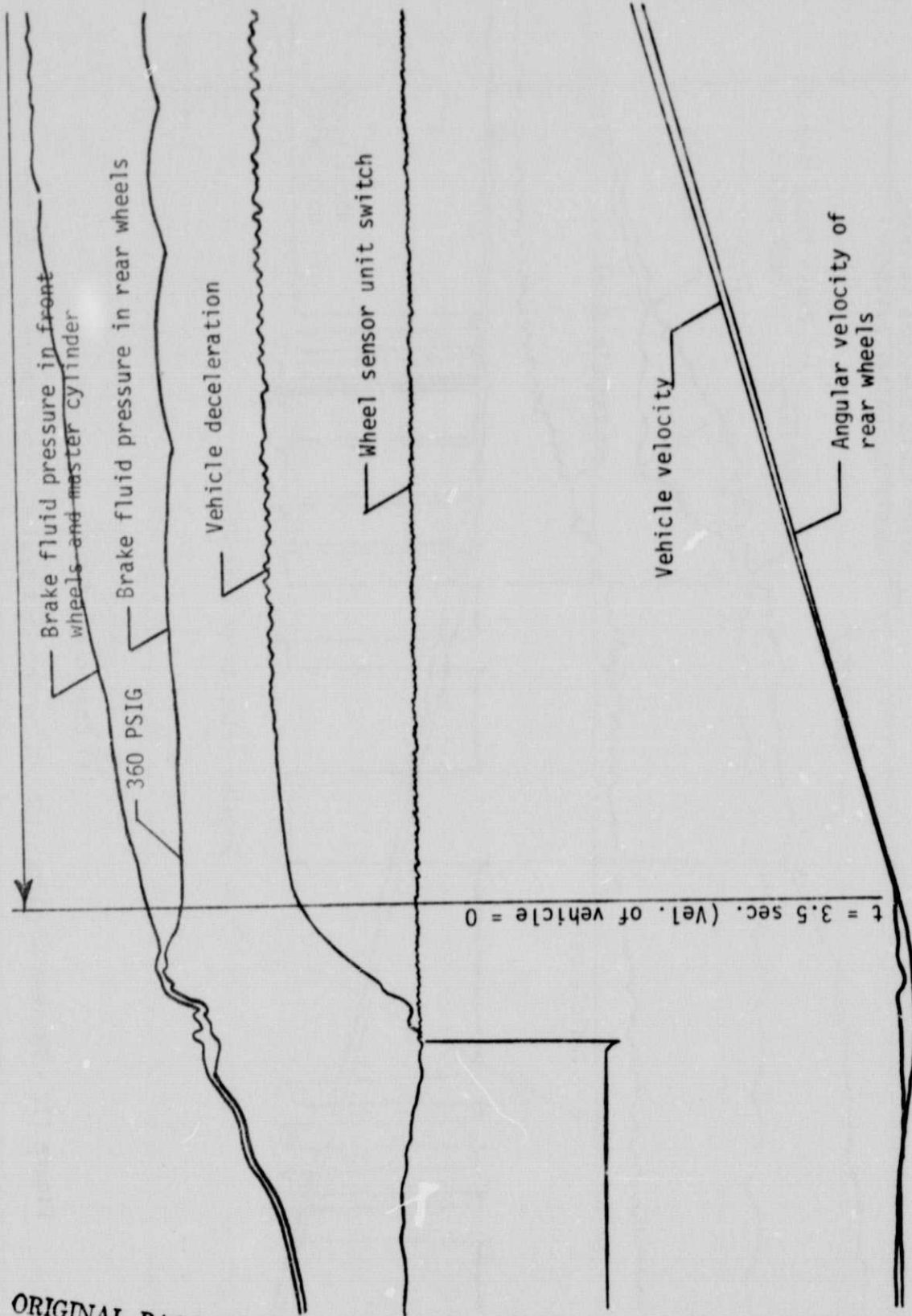
Figure 10. - Minimum distance stop using the test system - dry asphalt - 25 mph



(a) Beginning of run.

Figure 11. - Minimum distance stop using the test system - dry concrete - 50 mph





(b) End of run.  
Figure 11.- Concluded

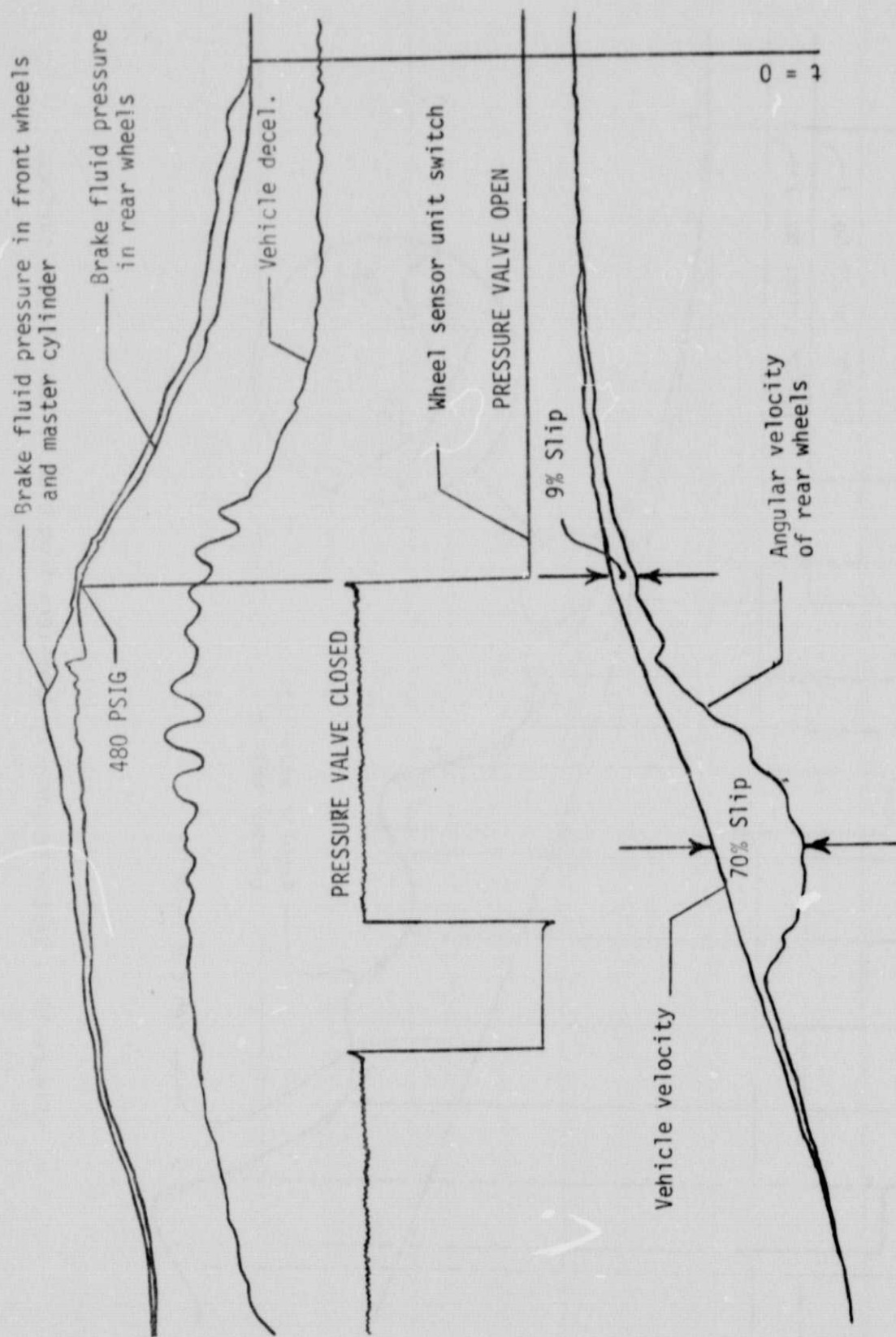


Figure 12. - Minimum distance stop using the test system - dry asphalt - 25 mph.

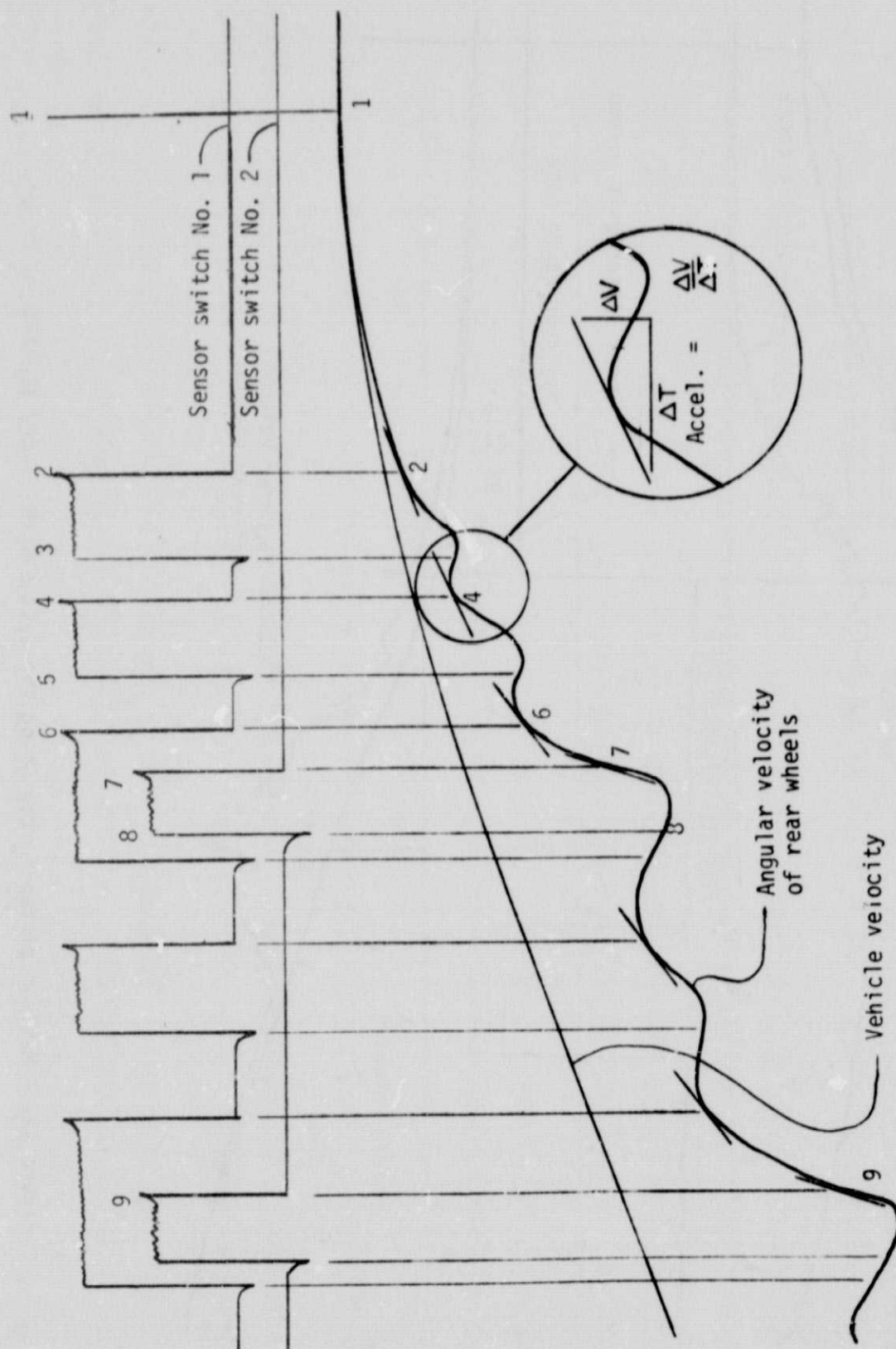


Figure 13. - System response to transfers from high to low friction surfaces